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LUMINARY Memo #181

To: Distribution
From: D. Millard
Date: 15 December 1970
Subject: IMU Alignments and LUMINARY 202

Reference: (1) MIT GSOP, LUMINARY 1C, Section 5

Tapes of LUMINARY revision 202 are being sent out to the simulators today. This memo is concerned with supplying details of the new sighting mark procedures (PCR 1044) and mark channel bit protection (PCR 333); both are now snug in revision 202. The following information is included - indexed for your convenience.

Briefly PCR 1044 proposes to eliminate the requirement of taking X and Y marks in pairs during inflight alignments and of taking cursor and spiral measurements in pairs during lunar surface alignments. To comply with 1044 it was necessary to devise a new computation scheme for processing mark data during lunar surface alignments. The computation scheme described in section 1 not only fulfills the requirements of PCR 1044 but also provides LUMINARY with a spin off, that being the capability of using the lunar surface sighting technique to accumulate sighting data during inflight alignments. An advantage of this added capability is that inflight IMU alignments can be performed under conditions where LM attitude is constrained as during the docked configuration.

Revision 202 does not provide for selecting the surface sighting technique during a P51; however this could be included with little coding impact. Section 3 describes the sighting option selection in P52.

PCR 333 was initiated to protect mark interrupts in the event that a ROD bit fails on during IMU alignments. Section 4 describes the back up mark capability gained under this PCR.

Level III type digital simulation runs have been made of P52, P57 and of P52 using the surface sighting technique.

SECTION 1

STAR VECTOR DETERMINATION

STAR VECTOR DETERMINATION FOR SURFACE ALIGNMENTS

The following equations describe the computation scheme used to determine the direction vector of a celestial body in platform coordinates from measurement data accumulated by AOT sightings. The data accumulated by the lunar surface sighting mark technique to determine a star direction are a cursor angle (YROT) and the CDU angles corresponding to the YROT mark time and a spiral angle (SROT) and the CDU angles corresponding to the SROT mark time. The cursor and spiral rotation angles are described in section 5.6.3.1.2 of reference 1.

The cursor mark data defines a plane containing both the sighted star and the optical axis of the AOT in platform coordinates. A spiral mark defines a spiral surface which also contains the sighted body. The line of intersection of the cursor plane $\underline{U}_{YP}$ and the spiral surface represents the direction of the star.

The normal to the cursor plane in body coordinates is computed by

$$\underline{U}''_{YPN} = -\sin(YROT)\,\underline{U}_{XPN} + \cos(YROT)\,\underline{U}_{YPN}$$

where $\underline{U}_{XPN}$ and $\underline{U}_{YPN}$ are plane vectors describing the AOT X and Y reticle lines in body coordinates given by equations 6.3.4 of reference 1.

The cursor plane vector with respect to platform coordinates at the cursor mark time is

$$\underline{U}_{YP} = [NBSM]_C\,\underline{U}''_{YPN}$$

$[NBSM]_C$ is the transformation matrix from body coordinates to platform coordinates using IMU CDU angles acquired by a cursor mark.

A unit vector $\underline{U}_{SP}$ is defined which sweeps along the spiral as a function of the angle θ as shown in Figure 1. With respect to the triple primed coordinate system $\underline{U}_{SP}$ is expressed by

$$\underline{U}_{SP} = (\cos\theta \sin\theta/12)\,\underline{U}'''_X - (\sin\theta \sin\theta/12)\,\underline{U}'''_Y + (\cos\theta/12)\,\underline{U}'''_Z$$

The axis vectors $\underline{U}'''_X$, $\underline{U}'''_Y$, $\underline{U}'''_Z$ are determined with respect to the body coordinate system using the measured spiral rotation angle (SROT).

$$\underline{U}'''_Y = -\sin(\text{SROT})\,\underline{U}_{XPN} + \cos(\text{SROT})\,\underline{U}_{YPN}$$

$$\underline{U}'''_Z = \underline{U}_{OAN}$$

$$\underline{U}'''_X = \text{UNIT}(\underline{U}'''_Y \times \underline{U}'''_Z)$$

$\underline{U}_{OAN}$ is a unit vector describing the optical axis of the AOT in body coordinates given by equation 6.3.1 of reference 1.

During lunar surface IMU alignments the initial estimate of θ is derived from the measured rotation angles.

$$\theta = 360 + \text{SROT} - \text{YROT}$$

If the surface sighting technique is used during inflight IMU alignments, θ is initially estimated using the sighting star vector stored in the LGC star catalog by transforming it to body coordinates and taking the dot product with the AOT optics axis vector.

$$\underline{\text{STAR}}_{NB} = [\text{SMNB}]_S \;\; \text{REFSMMAT}\;\underline{\text{STAR}}_{REF}$$

$[\text{SMNB}]_S$ is the transformation matrix from platform to body coordinates using IMU CDU angles acquired by a spiral mark.

$$\theta = 12\,\text{ARCCOS}(\underline{\text{STAR}}_{NB} \cdot \underline{U}_{OAN})$$

To obtain the line of intersection of the cursor plane and spiral surface a vector $\underline{U}_S$ must be computed which satisfies

$$\cos \phi = \underline{U}_{YP} \cdot \underline{U}_S = 0$$

where $\underline{U}_S$ is the spiral surface vector in platform coordinates.

$$\underline{U}_S = [NBSM]_S \, \underline{U}_{SP}$$

The iteration loop shown in the computation scheme flow diagram (Figure 2) is used to monitor convergence of cos ϕ where the initial computation of $\underline{U}_S$ is based on an initial estimate of θ. Subsequent computations of $\underline{U}_S$ use a θ incremented by $\pm$ 1 degree. The final solution for $\underline{U}_S$ represents the direction of the star in platform coordinates for a given set of mark data.

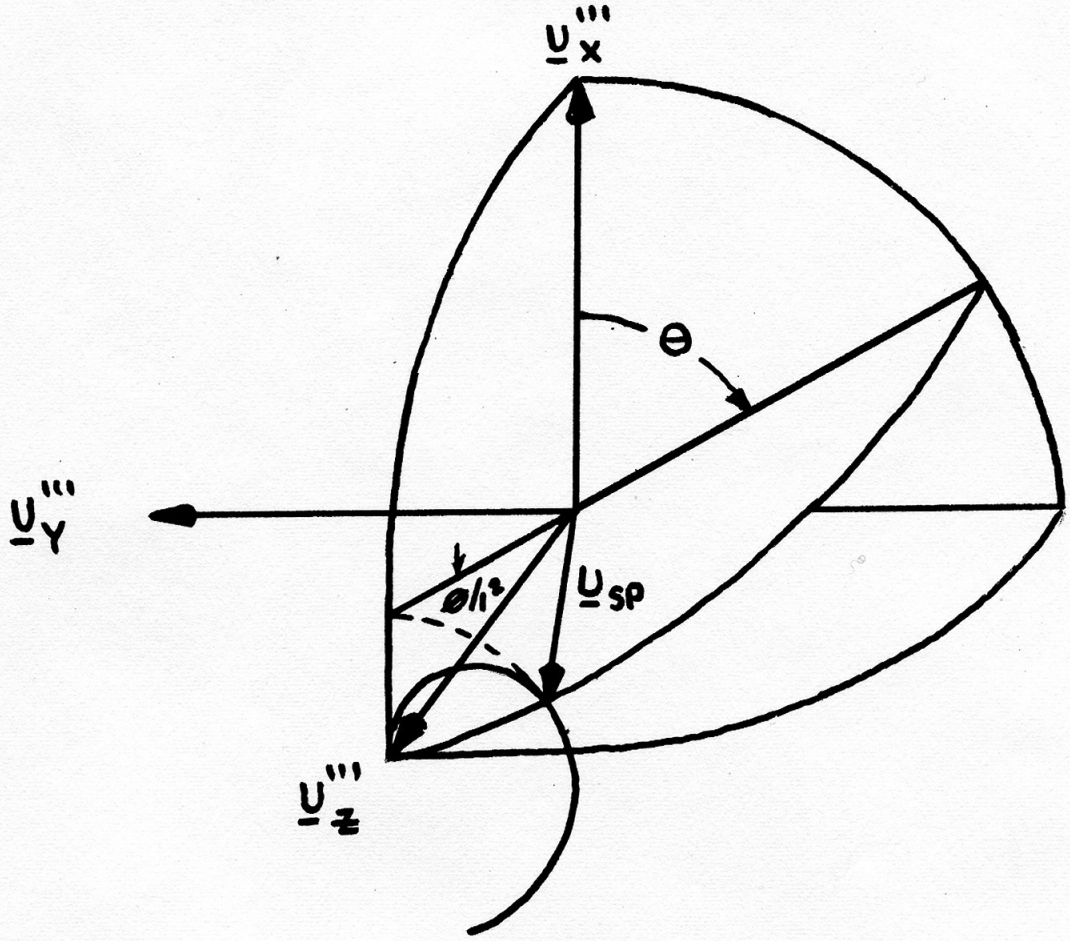

$\underline{U}'''_x$
$\underline{U}'''_y$
$\underline{U}'''_z$
θ
$\theta/2$
$\underline{U}_{SP}$

FIGURE 1

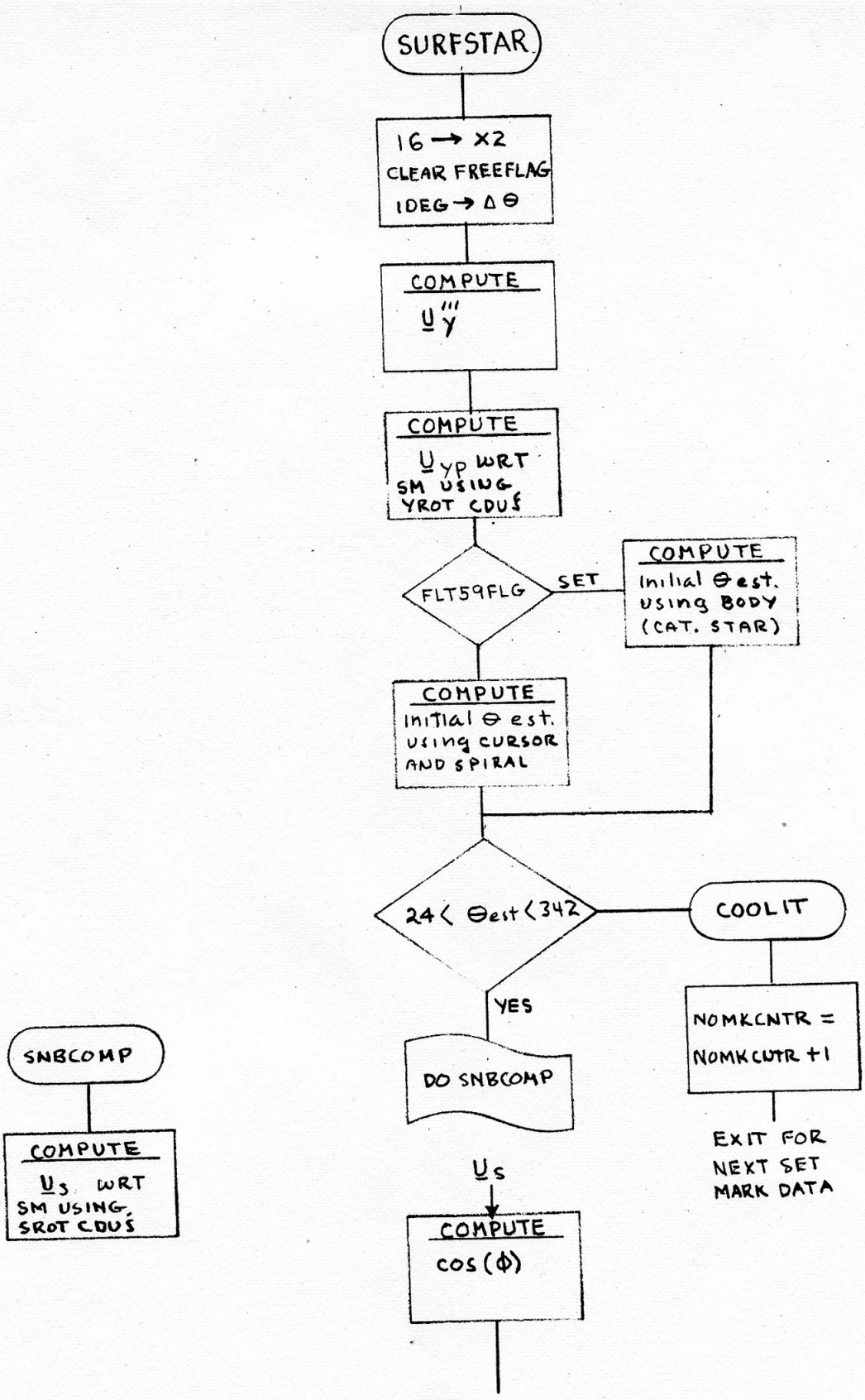
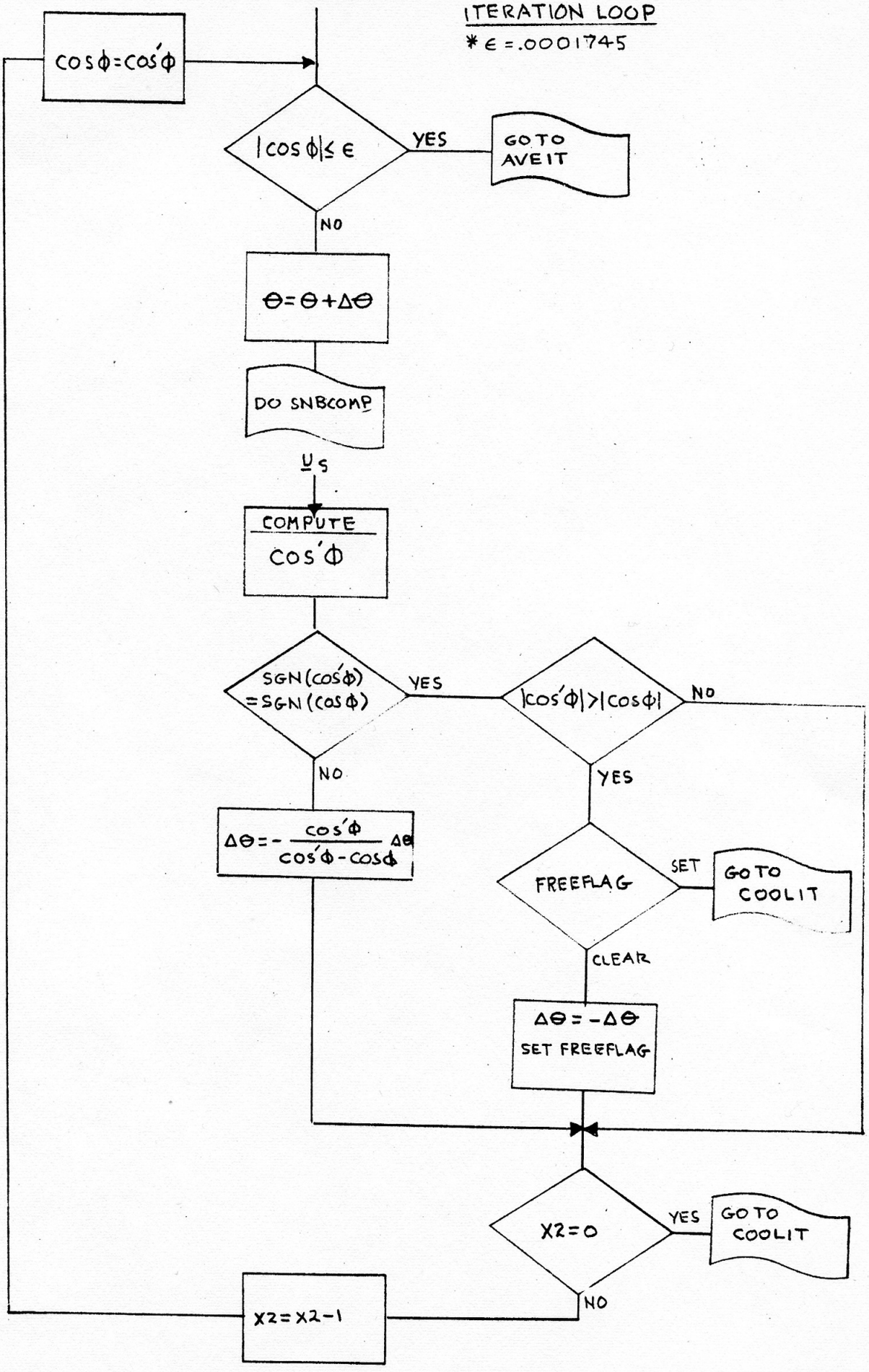

SURFSTAR
16 → X2
CLEAR FREEFLAG
1DEG → Δ Θ
COMPUTE
U'''y
COMPUTE
Uyp WRT SM USING YROT CDUS
FLT59FLG
SET
COMPUTE
Initial Θ est. using BODY (CAT. STAR)
COMPUTE
Initial Θ est. using CURSOR AND SPIRAL
24 < Θest < 342
COOLIT
YES
DO SNBCOMP
NOMKCNTR = NOMKCNTR +1
EXIT FOR NEXT SET MARK DATA
Us
COMPUTE
cos (Φ)
SNBCOMP
COMPUTE
Us WRT SM USING SROT CDUS

FIGURE 2


ITERATION LOOP
* ε = .0001745
cosφ=cos'φ
|cosφ|≤ ε
YES
GO TO AVEIT
NO
θ=θ+Δθ
DO SNBCOMP
U s
COMPUTE
cos'φ
SGN(cos'φ) =SGN(cosφ)
YES
|cos'φ|>|cosφ|
NO
NO
YES
Δθ=- cos'φ / cos'φ-cosφ Δe
FREEFLAG
SET
GO TO COOLIT
CLEAR
Δθ=-Δθ
SET FREEFLAG
X2=0
YES
GO TO COOLIT
NO
X2=X2-1

SECTION 2

SIGHTING MARK DISPLAYS

SIGHTING MARK DISPLAYS DURING INFLIGHT AND SURFACE ALIGNMENTS

V01 N71
R1 00DSS

This display appears at the start of the sighting mark procedure during both inflight and surface alignments. R1 shows the AOT sighting position code (D) and code (SS) of the celestial body the astronaut intends to use in the marking procedure. The astronaut may select another star and/or detent code by VERB 21 ENTER, OODSS ENTER.

PROCEED

Depressing PROCEED button
This action is taken when the astronaut wishes to start the MARKing sequence. If SURFFLAG or FLT59FLG is set the lunar surface sighting mark technique is to be used for this alignment and V52N71 will be displayed requesting a cursor mark. The above flags are clear for the normal inflight mark procedure and V54N71 will be displayed requesting the astronaut to perform X and Y MARKS.

TERMINATE

VERB 34, ENTER
The astronaut desires to terminate the alignment program. Verb 37 will be displayed.

V54 N71
R1 00DSS
R2 X MARKS
R3 Y MARKS

This display appears during the inflight sighting mark sequence. R1 contains the AOT position detent (D) and the octal star code (SS) of the celestial body to be marked. V54 requests the astronaut to take X and Y marks. He may make up to 5 X and Y marks in any sequence. The mark counters in registers R2 and R3 maintain a count of the accumulated X and Y marks. If more than 5 marks are made, the IMU CDU's stored by the 5th mark will be over written by the 6th mark. The mark counter will remain at 5. A pointer was added to the mark counter registers so the astronaut will always be aware of what his last mark was. This was primarily for MARK REJECT purposes because the last mark will be rejected first. This pointer is BIT 13 added to the mark counter register of the mark just performed. An example: if the astronaut had made 2 Y marks and had just performed the 4th X mark, the display would look like:

V54 N71
R1 00DSS
R2 10004
R3 00002

The reject pointer indicates an X mark was made and will be rejected with a MARK REJECT action. If that were the case R2 would be 10003 and further reject action would reduce the R2 counter to 10000 and cause ALARM 115 when there were no more X marks to be rejected. To give the astronaut some control of the reject action, a switch was provided with the ENTER button. Depressing the enter button flips the reject pointer to the opposite mark counter. An example: if the astronaut wanted to reject a Y mark in the above display, he would first depress the enter button to display:

V54 N71
R1 00DSS
R2 00004
R3 10002

The reject action would now cause R3 to be 10001.

During inflight alignments the position of the reject pointer in no way affects any sequence of marking the astronaut may wish to make. This is not the case during surface alignments. The marking sequence may be finished by one of the following astronaut actions.

PROCEED — Depressing the PROCEED button.
This action is taken when sufficient mark data has been accumulated. An average star vector is computed and program control returns to the alignment program. It is not necessary that the same number of X and Y marks be made; however, the number of star vectors computed and averaged will be equal to the mark counter with the least number of marks. ALARM 111 will occur if either mark counter is zero.

RECYCLE — VERB 32 ENTER
With this action the astronaut may select another star and/or detent code for the mark sequence. V01N71 will be redisplayed.

TERMINATE — VERB 34 ENTER
The astronaut desires to terminate the alignment program. Verb 37 will be displayed.

V52 N71/V53 N71 These two mark requests appear during the lunar
R1 00DSS surface sighting sequence. V52 is displayed first
R2 YROT MARKS requesting the astronaut to perform cursor measure-
R3 SROT MARKS ments by rotating the AOT reticle pattern until the cursor line is coincident with a star and depressing a mark button. V53 requests the astronaut to perform spiral measurements by rotating the reticle pattern to bring the spiral line on the star and depressing a mark button. Up to 5 marks may be accumulated. Registers R2 and R3 maintain a count of the marks. When the astronaut performs a cursor mark by depressing the MARK button under V52 N71, V21 N79 is displayed requesting the cursor angle load. When the angle is ENTERed, V06 N79 is displayed for data verification and a PROCEED causes the cursor data to be stored and V52 N71 is redisplayed requesting another cursor mark.

In the surface sighting technique the enter button not only controls the reject pointer as during the inflight sighting procedure but is also the method by which the astronaut selects which measurement, cursor or spiral, he intends to perform. After sufficient cursor marks are accumulated under V52 N71 an ENTER is executed which causes V53N71 to be displayed requesting spiral measurements. Depressing the MARK button under V53 N71 causes the spiral load request V22 N79 to be displayed. When the spiral angle is ENTERed V06N79 is displayed for data verification and a PROCEED brings up V53N71 requesting another spiral mark. Mark data will only be accepted when a mark verb is displayed. Depressing the MARK button under any other display will cause ALARM 112. The surface marking sequence may be ended by one of the following actions.

PROCEED Depressing the PROCEED button.
This action is taken after sufficient mark data has been accumulated. An average star vector is computed

and program control returns to the alignment program. The computation scheme used to compute the star vectors from data collected by the lunar surface marking technique can reject mark data sets, i.e., CDU's, cursor and spiral, for a given mark. If, during the computation, any data is rejected the display V50N25, R1 = 00016 will appear after all computation is completed. Register R2 will contain the number of data sets rejected. This display is discussed later. If either mark counter is zero ALARM 111 is indicated and V52 N71 will be redisplayed.

RECYCLE — VERB 32 ENTER

With this action the astronaut may select another star and/or detent code for the marking sequence. V01 N71 will be displayed.

TERMINATE — VERB 34 ENTER

The astronaut wishes to terminate the alignment program. V37 will be displayed.

V50 N25
R1 00016
R2 0000R

This display appears only during the lunar surface marking procedure and then only if mark data is rejected during the computation of star vectors after the marking sequence. Register R2 displays the number (R) of mark data sets rejected. Data for a given sighting mark is rejected if the star is within 2 degrees of the AOT optic axis or if the star lies on the edge of the AOT field-of-view greater than 28.5 degrees from the optic axis. Data is also rejected if more than 16 iterations are required to converge to a solution or if the sign of the iteration step changes more than once. The following action is possible.

PROCEED

Depressing PROCEED
The astronaut wishes to proceed with the alignment using the average star vector computed from non-rejected mark data.

RECYCLE

VERB 32 ENTER
The astronaut chooses to redo the sighting mark. V01 N71 will be displayed.

TERMINATE

VERB 34 ENTER
The astronaut desires to terminate the alignment program. V37 will be displayed.

SECTION 3

SIGHTING TECHNIQUE SELECTION

SELECTION OF INFLIGHT SIGHTING TECHNIQUE

V50 N25
R1 00015

This display appears at the start of the Fine Align Routine R51, during inflight alignments. It requests the astronaut to perform celestial body acquisition either manually or automatically by using the inflight PICAPAR routine or the Lunar Surface Star Acquisition Routine by selecting one of the following responses.

PROCEED

Depress PROCEED button
The astronaut wishes to use the PICAPAR Routine to locate two stars with respect to the AOT forward sighting position for the present LM attitude. If two stars are found the Auto Optics Position Routine will display V01 N70 with the number of the first star to be sighted in R1. If stars are not found V05 N09 with alarm code 00405 in R1 will be displayed. The astronaut may maneuver the LM to a different attitude and recycle the display, V32E, to V50 N25 and try PICAPAR again or he may ENTER to V01 N70 and select a star.

RECYCLE

VERB 32 ENTER
The astronaut wishes to use the lunar surface sighting technique to accumulate sighting mark data. FLT59FLG is set and the program branches to the Lunar Surface Star Acquisition Routine and V01 N70 is displayed.

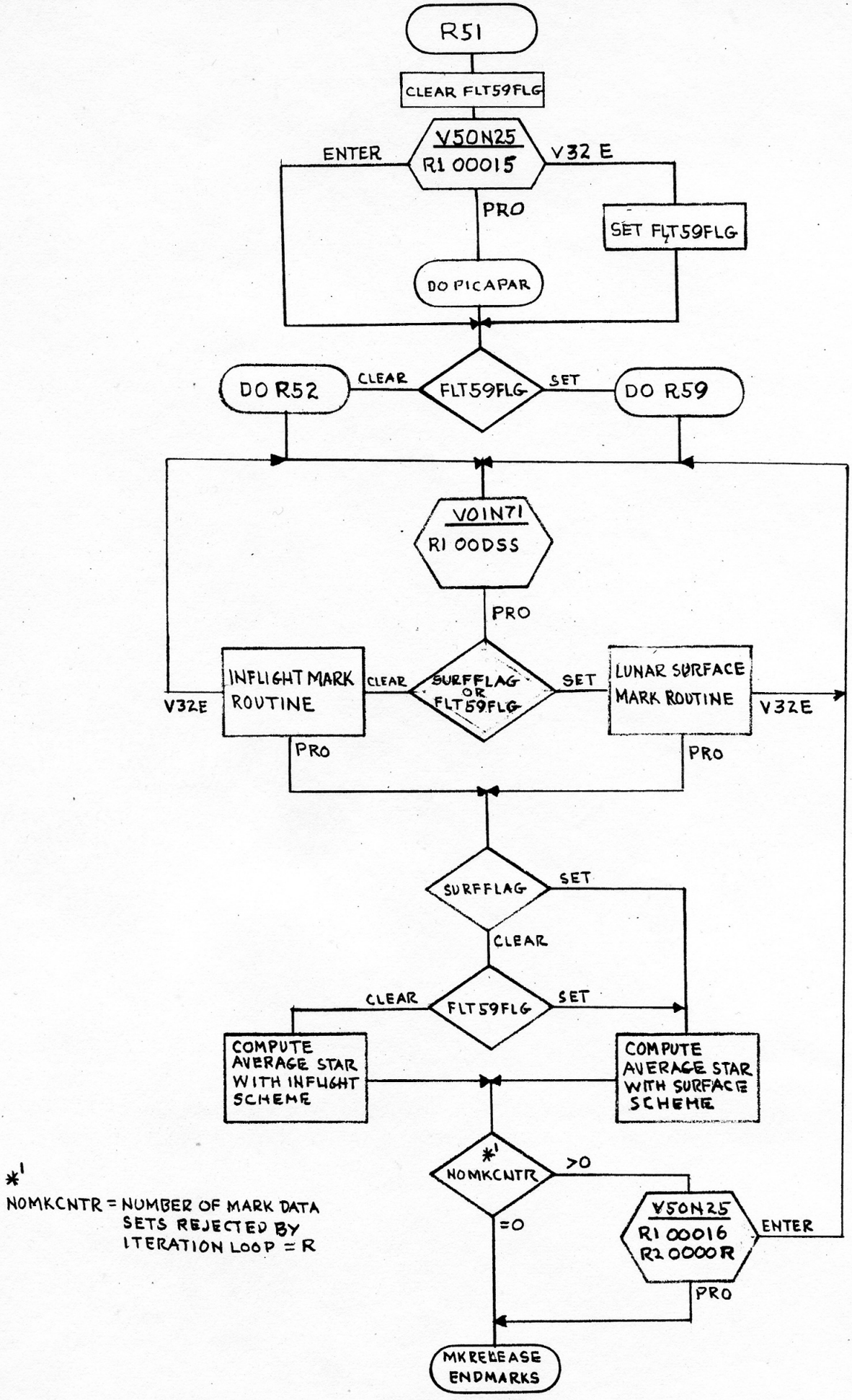
ENTER

Depress ENTER button
The astronaut wishes to bypass the PICAPAR Routine. V01 N70 from the Auto Optics Position Routine will be displayed.

TERMINATE

VERB 34 ENTER
The astronaut desires to terminate the alignment program. V37 will be displayed.

The following diagram shows the program flow in R51 and R53 for the inflight and lunar surface sighting techniques.



*1

NOMKCNTR = NUMBER OF MARK DATA SETS REJECTED BY ITERATION LOOP = R

SECTION 4

PCR 333 AND BACKUP MARKING CAPABILITY

BACK UP MARK CAPABILITY

PCR 333 provides for protecting the X and Y mark interrupts in the event that a ROD bit fails on in channel 16 during IMU alignments. Since it is also possible for a mark bit failure to equally jeopardize on-board alignment capability, implementation of the PCR was coded to cause ROD input to be utilized as a mark interrupt during non-thrusting periods. To prevent all mark interrupts from looking like a mark reject in the event of reject bit failure, ROD interrupt logic bypasses the interrogation of channel 16 for reject action. A mark reject can always be accomplished by VERB 32 ENTER under the MARK VERB display which cycles the display to V01N71. This action not only eliminates the offending mark but also all good marks that may have been accumulated for a given star, but it does save from having to reselect the alignment program.

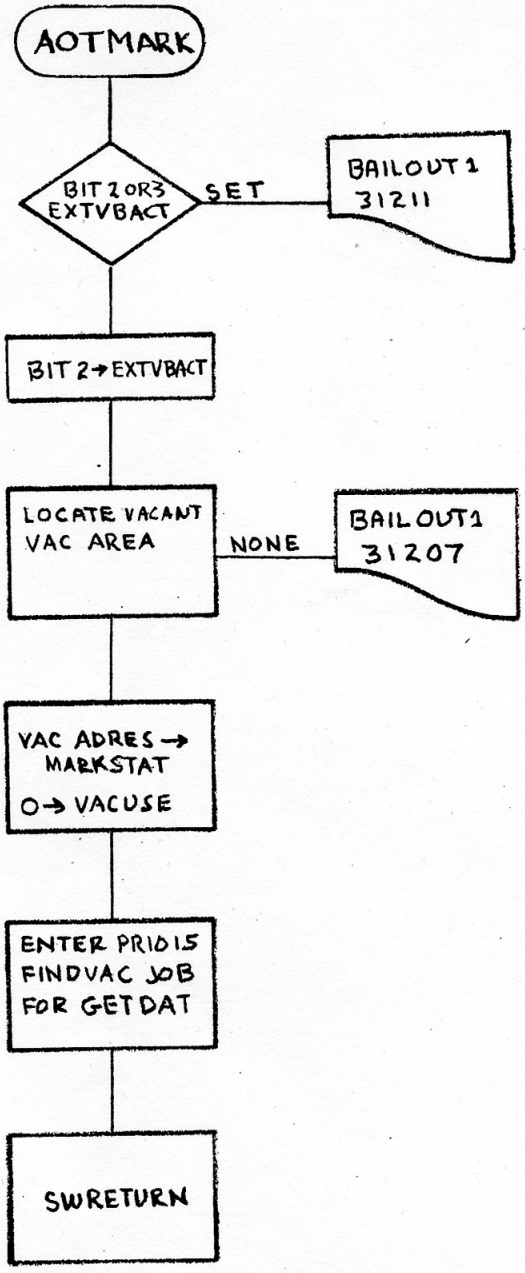
If a ROD bit does fail during an IMU alignment it will probably go unnoticed since the MARK bit gets processed normally. If a mark reject is attempted, however, ALARM 113 will result indicating no channel bit since ROD logic bypasses the reject bit interrogation.

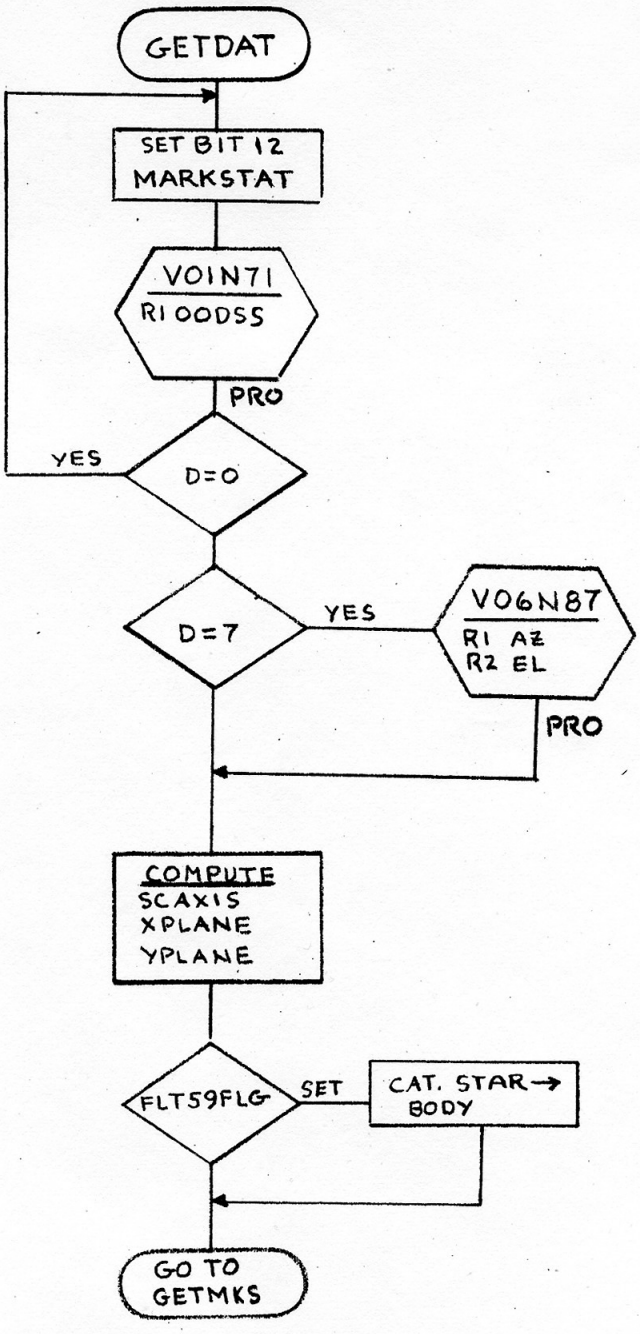
In the event of an X or Y mark bit failure the Lunar Surface Sighting Mark technique is used for the back-up procedure since it is not particular how the mark interrupt occurs; i.e. X MARK or Y MARK. Section 3 describes the sighting technique selection. The cursor and spiral marks are made by activating the ROD Switch. For Lunar surface alignments the back up capability is automatically present. Activating the ROD switch under a display other than a mark request verb will cause ALARM 112 if AVEGFLAG is clear.

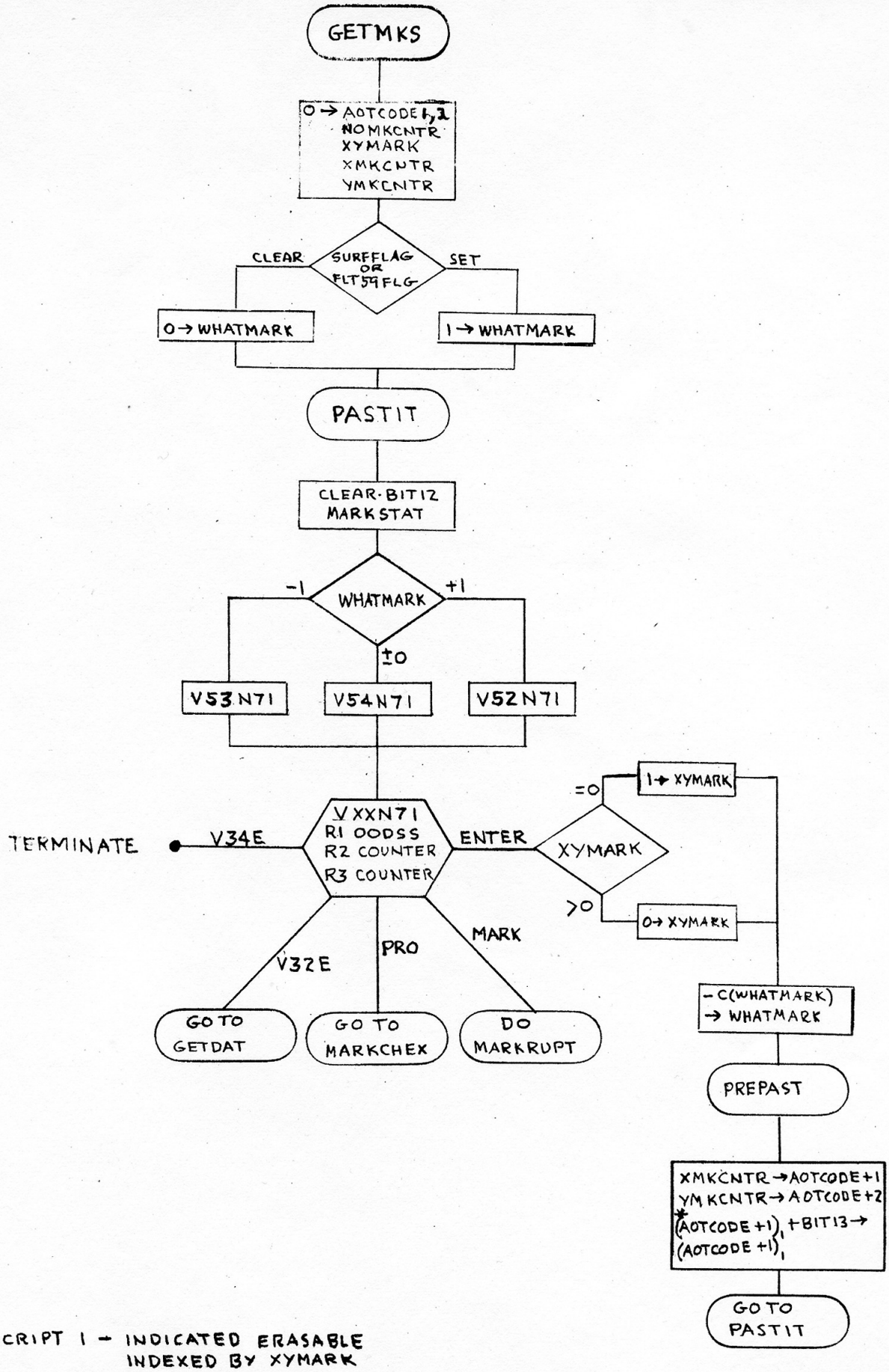
Page 5 of section 5 shows the flow logic of PCR 333 in the MARKRUPT Routine.

SECTION 5

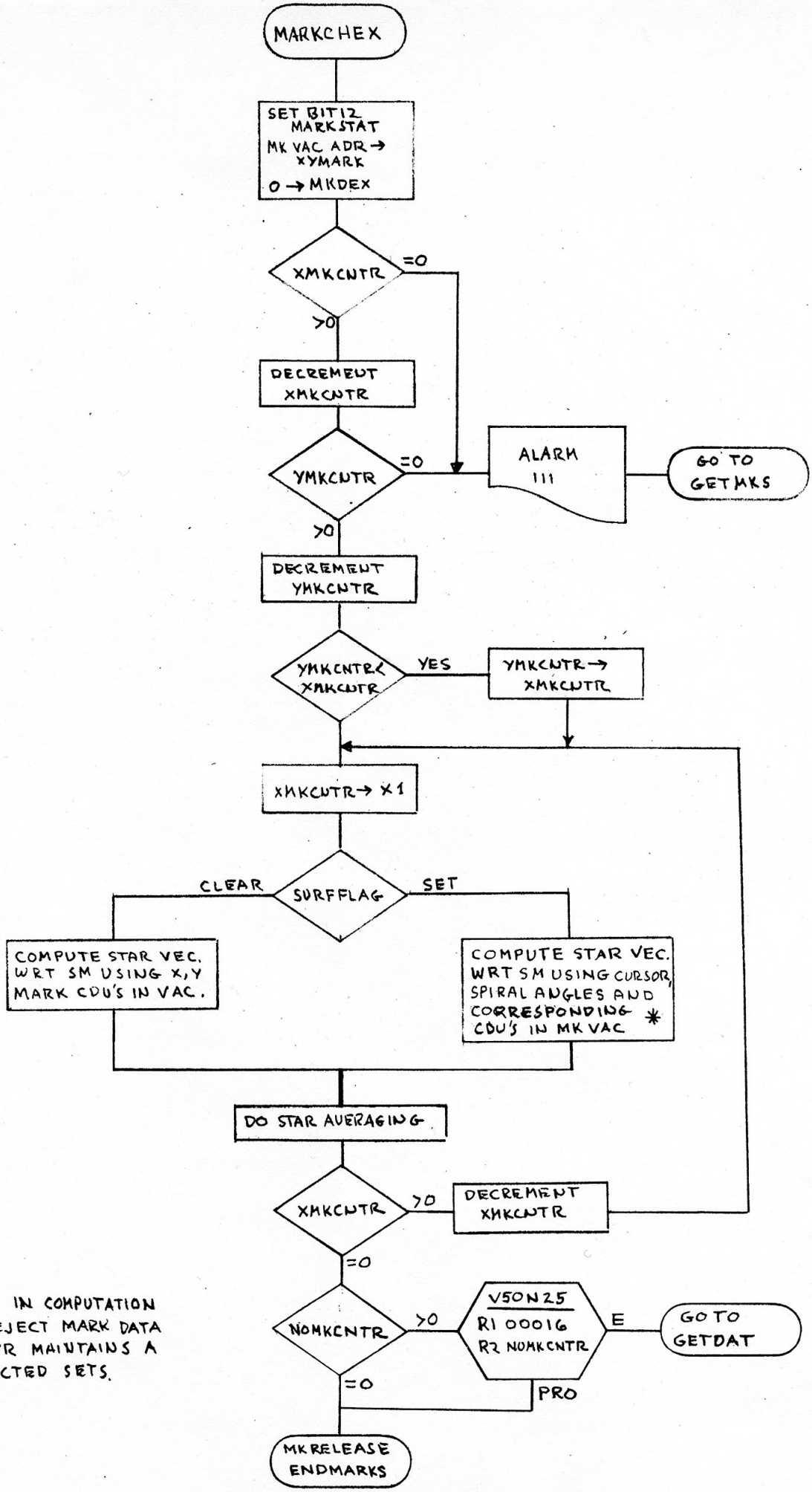
DETAIL FLOW DIAGRAMS (R53)


AOTMARK
BIT 2 OR 3 EXTVBACT
SET
BAILOUT 1 31211
BIT 2 → EXTVBACT
LOCATE VACANT VAC AREA
NONE
BAILOUT 1 31207
VAC ADRES → MARKSTAT
0 → VACUSE
ENTER PRIO 15 FINDVAC JOB FOR GETDAT
SWRETURN

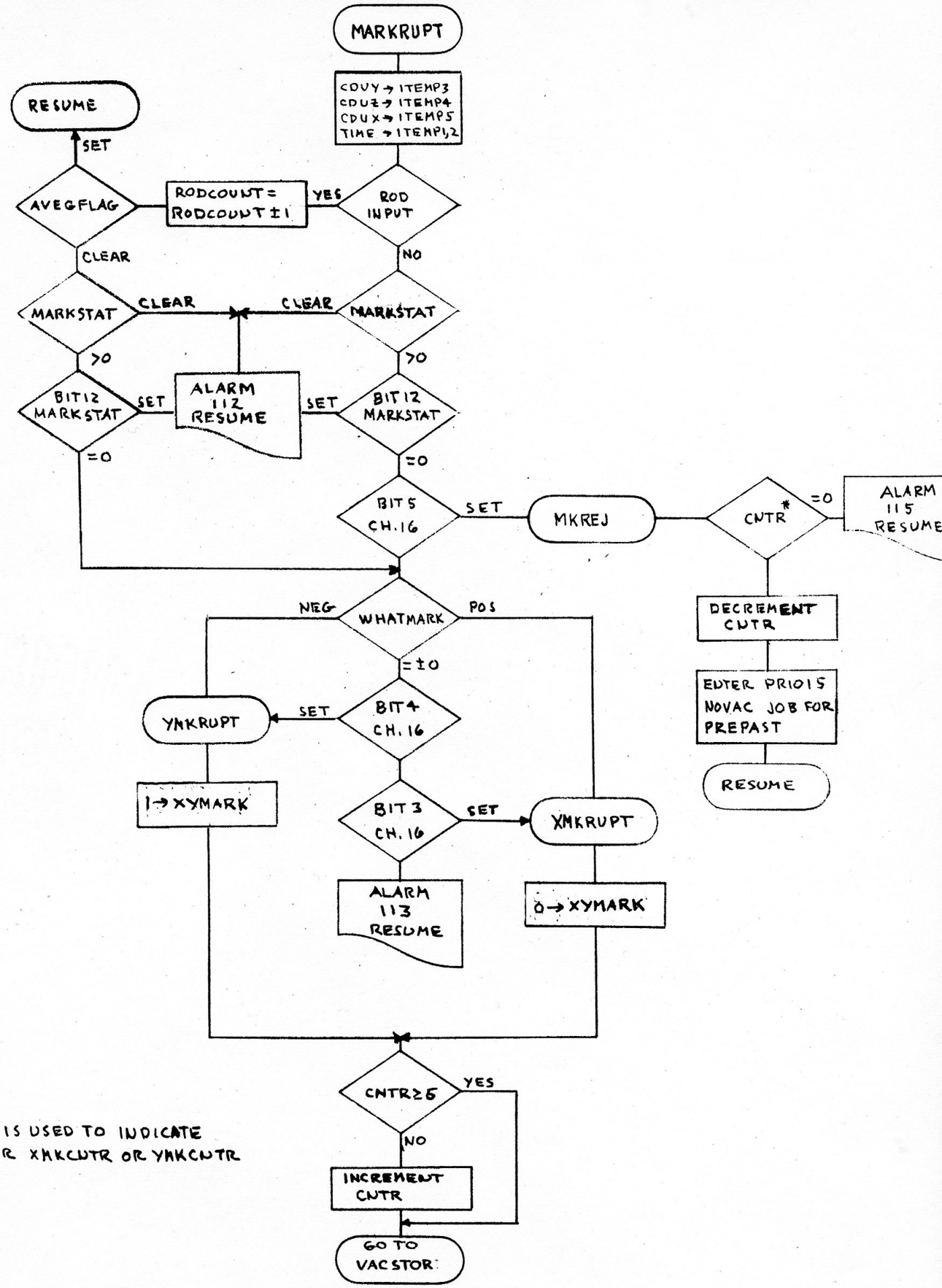

GETDAT
SET BIT 12
MARKSTAT
VOIN71
R1 OODSS
PRO
YES
D=0
D=7
YES
V06N87
R1 AZ
R2 EL
PRO
COMPUTE
SCAXIS
XPLANE
YPLANE
FLT59FLG
SET
CAT. STAR→
BODY
GO TO
GETMKS



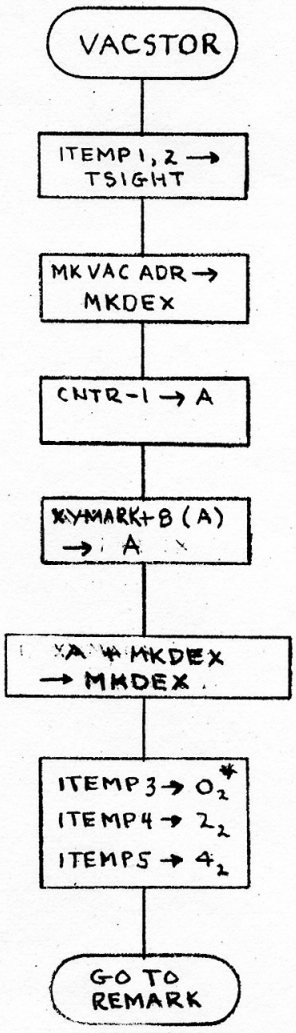
*
SUBSCRIPT 1 – INDICATED ERASABLE
INDEXED BY XYMARK



*
ITERATION LOOP IN COMPUTATION SCHEME CAN REJECT MARK DATA SETS. NOMKCNTR MAINTAINS A COUNT OF REJECTED SETS.

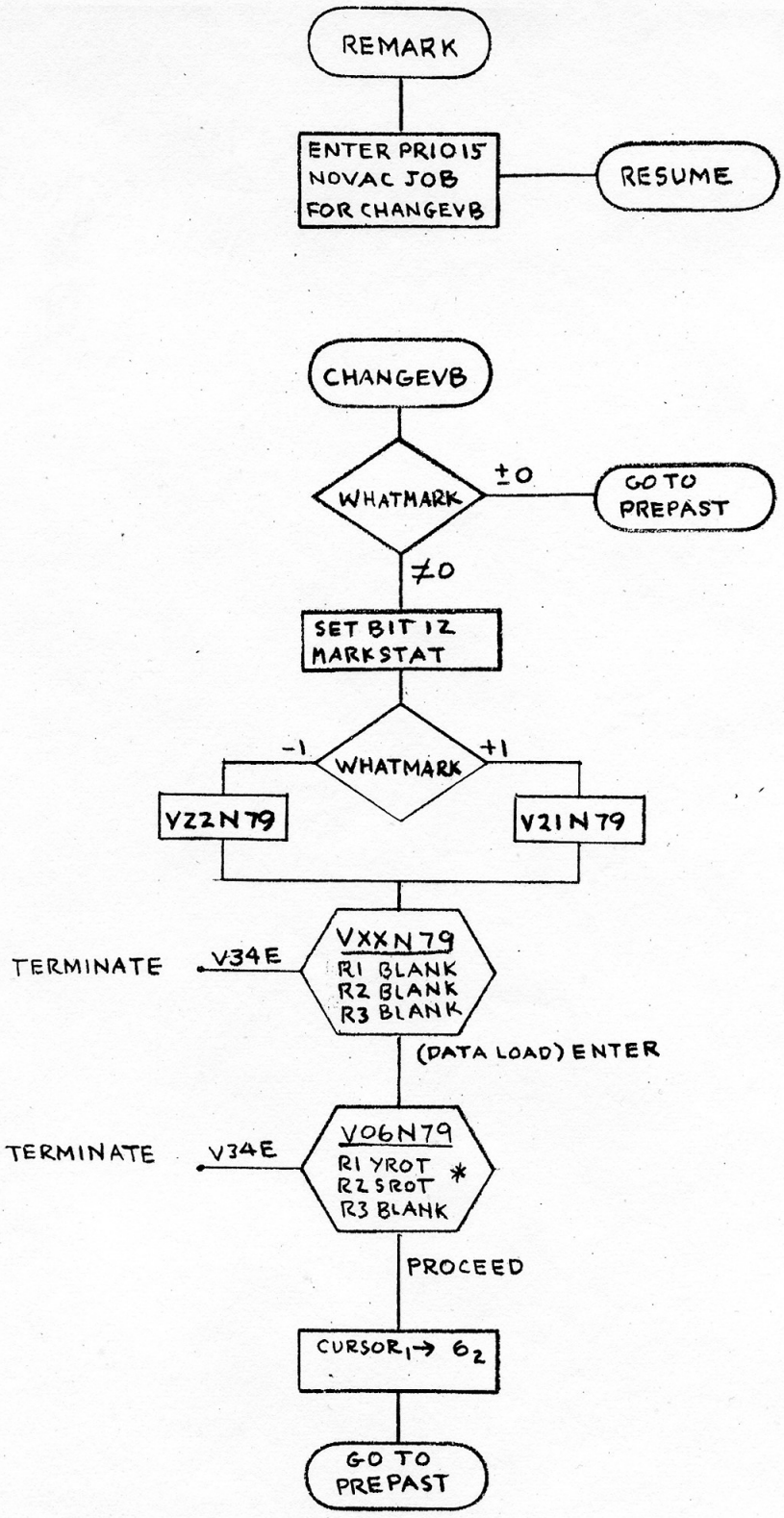


*
CNTR IS USED TO INDICATE
EITHER XMKCNTR OR YMKCNTR



*

SUBSCRIPT 2 – INDICATED STORAGE LOCATION INDEXED BY MKDEX



*

IF XYMARK = 0, BLANK R2, R3

IF XYMARK = 1, BLANK R1, R3

SECTION 6

LM IMU ALIGNMENT CHECKLIST

APOLLO 15

P51 IMU ORIENTATION

1 CB (11) AC BUS B: AOT LAMP-Close
V37E 51E
F 50 25 R1 00015 MNVR TO ACQ STARS
(To Coarse Align IMU To 0, 0, 0-ENTR)
41 22 A11 Zeroes
PRO

2 F 01 71 R1 00CDE (C) DETENT (DE) STAR CODE
C 1-L, 2-F, 3-R, 4-RR, 5-CL, 6-LR
7-COAS (+00000, +00000) FWD
(+00000, +09000) OVHD
PRO
(FOR C=7)
F 06 87 AZ, EL ($.01^{o}$)
PRO

3 F 54 71 MARK X OR Y
R1 00CDE
R2 X MARKS
R3 Y MARKS
1000X in R2/R3 indicates reject enable
(CHANGE REJECT OPTION) ENTER
(REDESIGNATE) V32E to 2
(MARKS COMPLETE) PRO
(For DE=00
F 06 88 CELESTIAL BODY VECTOR
Load Vector Values
PRO)
(After 1st Star) To 2
(After 2nd Star) To 4

4 F 06 05 R1 STAR ANGLE DIFFERENCE ($.01^{o}$)
(RECYCLE) V32E To 1
PRO

5 F 37 CB (11) AC BUS B: AOT LAMP-Open

P52 IMU REALIGN

1 CM (11) AC BUS B: AOT LAMP-Close
V37E 52E

F 04 06 R1 00001 IMU ALIGN OPT
R2 00001 PREF (0, 0, 0 Specified Attitude)
PRO To 4
2 NOM (LV At Specified Time)
PRO To 2
3 REFSMMAT PRO To 6
4 LANDING SITE PRO To 2

2 F 06 34 GET ALIGN (hrs, min, .01 sec)
(0, 0, 0 For Present Time)
(TLAND FOR OPT 4)
(OPT 2) PRO To 4
(OPT 4) PRO To 3

3 F 06 89 LAT, LONG/2, ALT ($.001^{o}$, .01nm)
PRO

4 F 06 22 NEW ICDU ANGLES OG, IG, MG ($.01^{o}$)
(IF MGA NEAR GIMBAL LOCK, MNVR, Then V32E To 4)
PRO

5 F 50 25 R1 00013 (COARSE ALIGN)
(NORMAL) PRO To 6, NO ATT Lt-On Then Off
(GYRO TORQUE) MODE CONT (PGNS)-ATT HOLD, V76E
ENTR

16 20 PRESENT ICDU ANGLES OG, IG, MG ($.01^{o}$)
When Torquing Complete To 20

6 F 50 25 R1 00015 SELECT STAR ACQUISITION MODE
MNVR If Necessary
(PICAPAR) PRO
*F 05 09 00405 NO PAIR *
*(CREW SPECIFY) PRO To 7 *
*(PICAPAR) V32E To 6 *
(MAN ACQ) ENTR
(USE CURSOR/SPIRAL) V32E To 7

7 F 01 70 R1 00CDE (C) DETENT (DE) STAR CODE
C 0 -COAS/LPD CALIBRATION
1-L, 2-F, 3-R, 4-RR, 5-CL, 6-LR
7-COAS (+00000, +00000) FWD
(+00000, +09000)OVHD
(TERM) V34E
PRO
(For C=0 or 7
F 06 87 AZ, EL ($.01^{o}$)
PRO)
(For DE=00

F 06 88 CELESTIAL BODY VECTOR
Load Vector Values
PRO)

*PROG Lt-On
F 05 09 00404 Defined Star
* Not Available In *
* Any Detent *
(CREW SPECIFY) PRO to 10
*(LGC CALC N79) V32E To 7

(For CURSOR/SPIRAL
F 06 79 CURSOR, SPIRAL, POS CODE
(REDESIGNATE) V32E To 7
PRO To 10)

*PROG Lt - On *
*V05N09E *
* 20105 AOT Mark System*
* In Use *
* 31207 No VAC Area *
* For Marks *
* 31211 Illegal *
* Interrupt of *
* Extended Verb *
*V37E XXE *

8 F 50 18 REQUEST MNVR TO FDAI RPY ANGLES (.01°)
(AUTO OR TRIM) GUID CONT - PGNS
MODE CONT (PGNS) - AUTO
PRO
(MAN) MODE CONT (PGNS) - ATT HOLD
MNVR
PRO To 8
(BYPASS)ENTR To 10 (If COAS/LPD CALIB, Go to 7)

9 06 18 AUTO MNVR TO FDAI RPY ANGLES (.01°)
Mon Auto Mnvr To 8

10 F 01 71 R1 00CDE (C) DETENT (DE)STAR CODE
PRO
(For C=7
F 06 87 AZ, EL (.01°)
PRO)
(For CURSOR/SPIRAL) GO TO 12

11	F 54 71	MARK X OR Y R1 00CDE R2 X MARKS R3 Y MARKS 1000X in R2/R3 indicates reject enable (CHANGE REJECT OPTION) ENTER (REDESIGNATE) V32E To 10 (MARKS COMPLETE) PRO (For DE = 00 F 06 88 CELESTIAL BODY VECTOR LOAD VECTOR VALUES PRO) (After first star) To 7 (After second star) To 18
12	F 52 71	MARK CURSOR (5 maximum) R1 00CDE R2 CURSOR MARKS R3 SPIRAL MARKS 1000X IN R2/R3 indicates reject enable (REDESIGNATE) V32E To 10 (CHANGE REJECT OPTION AND REQUEST SPIRAL MARKS) ENTER To 15 (MARKS COMPLETE) PRO POSS F 50 25 R1 00016 R2 0000X X = NO. MARK DATA SETS REJECTED (TAKE MORE MARKS) ENTER To 10 (BYPASS) PRO (For DE = 00 F 06 88 CELESTIAL BODY VECTOR LOAD VECTOR VALUES PRO) (After first star) To 7 (After second star) To 18 MARK (X OR Y)
13	F 21 79	LOAD CURSOR ANGLE
14	F 06 79	R1 CURSOR ANGLE (VERIFY) PRO To 12
15	F 53 71	MARK SPIRAL (5 maximum) R1 00CDE R2 CURSOR MARKS R3 SPIRAL MARKS 1000X IN R2/R3 indicates reject enable (REDESIGNATE) V32E To 10 (CHANGE REJECT OPTION AND REQUEST CURSOR MARKS) ENTER TO 12 (MARKS COMPLETE) PRO POSS FL 50 25 R1 00016 R2 0000X

X = NO. MARK DATA SETS REJECTED
(TAKE MORE MARKS) ENTER TO 10
(BYPASS) PRO
(For DE = 00
F 06 88 CELESTIAL BODY VECTOR
LOAD VECTOR VALUES
PRO)
(After first star) to 7
(After second Star) to 18
MARK (X OR Y)

16 F 22 79 LOAD SPIRAL ANGLE

17 F 06 79 R2 SPIRAL ANGLE (VERIFY)
PRO to 15

18 F 06 05 STAR ANGLE DIFFERENCE ($.01^{o}$)
(REJECT) V32E To 20
(ACCEPT) PRO

19 F 06 93 GYRO ANGLES X, Y, Z ($.001^{o}$)
(TORQUE) MODE CONTROL (PGNS) - ATT HOLD
V76E
PRO
(NO TORQUE) V32E To 20

20 F 50 25 R1 00014
(RECHECK) PRO To 6
(EXIT) ENTR

21 F 37 CB (11) AC BUS B: AOT LAMP-OPEN

P57 LUNAR SURFACE ALIGNMENT

1 V37E57E

*PROG Lt - On *
*V05N09E 00210 IMU *
* NOT ON *
CB(11) PGNS: IMU OPR - Close
*RSET & KEY REL, P57E *

F 04 06 R1 00001 IMU ALIGN OPT
R2 00001 PREF PRO To 3
3 REFSMMAT PRO To 3
4 LANDING SITE PRO To 2

2 F 06 34 T ALIGN (hrs, min, .01sec)
(LDG SITE) T ALIGN = 0, 0, 0 For Present Time
PRO

3 F 05 06 R1 00010 SPECIFY ALIGNMENT TECHNIQUE (A/T)
R2 0000X
X = 0 Stored Attitude or REFSMMAT
1 REFSMMAT & Gravity
2 Celestial Bodies (2)
3 Gravity & Celestial Body (1)
R3 00CD0
C = 0 No REFSMMAT Defined
1 REFSMMAT Defined
D = 0 No Stored Attitude
1 Stored Attitude Available

(A/T 1 or 3) ATT MON - PGNS, PRO To 4
(IMU ON & ALIGNED & A/T 0) PRO To 18
(IMU ON & ALIGNED & A/T 2) PRO To 6
(IMU NOT ALIGNED & A/T 0 or 2) PRO To 17

*PROG Lt - On *
*F 05 09 00701 REFSMMAT OR *
* ATTITUDE NOT AVAILABLE*
*(CHANGE A/T) V32E To 3 *
*(TERM) V34E, Select New Prog *

4 Monitor of Lunar Gravity Measurement
V16N20E Monitor Coarse Align (.01°)
R1 +04200
R2 +31800
R3 + 03525
NO ATT Lt - On Then Off (Twice)
*PROG Lt - On *

V05N09E 00211 & 00217
KEY REL

5 F 06 04 (+) GRAVITY ERROR ANGLE ($.01^{o}$)
(RECYCLE) V32E To 4
(TERM) V34E, Select New Prog
PRO To 17

6 F 01 70 R1 00CDE (C) DETENT (DE) STAR CODE
(DETENT) 1-L, 2-F, 3-R, 4-RR, 5-CL, 6-LR
PRO

(For DE = 00
F 06 88 CELESTIAL BODY VECTOR
Load Vector Values
PRO)

*PROG Lt - On
*F 05 09 00404 Defined Star *
* Not Available In *
* Any Detent *
(CREW SPECIFY) PRO To 8
(LGC CALC N79) V32E To 6

7 F 06 79 CURSOR, SPIRAL, POSITION CODE ($.01^{o}$)
(REDEFINE STAR) V32E To 6
PRO

*PROG Lt - On *
*V05N09E *
* 20105 AOT Mark System*
* In Use *
* 31207 No VAC Area *
* For Marks *
* 31211 Illegal *
* Interrupt of *
* Extended Verb *
*V37E XXE *

8 F 01 71 R1 00CDE (C) DETENT, (DE) STAR CODE
PRO

9 F 52 71 MARK CURSOR (5 maximum)
R1 00CDE
R2 CURSOR MARKS
R3 SPIRAL MARKS
1000X IN R2/R3 indicates reject enable
(REDESIGNATE) V32E To 8
(CHANGE REJECT OPTION AND REQUEST
SPIRAL MARKS) ENTER TO 12

(MARKS COMPLETE) PRO
POSS F 50 25 R1 00016
R2 0000X
X = NO. MARK DATA SETS REJECTED
(TAKE MORE MARKS) ENTER To 8
(BYPASS) PRO
(For DE = 00
F 06 88 CELESTIAL BODY VECTOR
LOAD VECTOR VALUES
PRO)
(After First Star) To 6 (If option 00003 to 15)
(After Second Star) To 15
MARK (X OR Y)

10 F 21 79 LOAD CURSOR ANGLE

11 F 06 79 R1 CURSOR ANGLE(VERIFY)
PRO To 9

12 F 53 71 MARK SPIRAL (5 maximum)
R1 00CDE
R2 CURSOR MARKS
R3 SPIRAL MARKS
1000X in R2/R3 indicates reject enable
(REDESIGNATE) V32E To 8
(CHANGE REJECT OPTION AND REQUEST CURSOR MARKS) ENTER To 9
(MARKS COMPLETE) PRO
POSS FL 50 25 R1 00016
R2 0000X
X = NO. MARK DATA SETS REJECTED
(TAKE MORE MARKS) ENTER To 8
(BYPASS) PRO
(For DE = 00
F 06 88 CELESTIAL BODY VECTOR
LOAD VECTOR VALUES
PRO)
(After First Star) To 6 (If option 00003 to 15)
(After Second Star) To 15
MARK (X OR Y)

13 F 22 79 LOAD SPIRAL ANGLE

14 F 06 79 R2 SPIRAL ANGLE (VERIFY)
PRO To 12

15	F 06 05	STAR ANGLE DIFFERENCE (REJECT) V32E To 18 (ACCEPT) PRO (TERM) V34E	(.01°)
16	F 06 93	GYRO TORQUING ANGLES X, Y, Z (REJECT) V32E To 18 (ACCEPT) PRO To 18 (TERM) V34E	(.001°)
17	F 06 22	ICDU ANGLES OG, IG, MG PRO NO ATT Lt - On Then Off (If A/T 2 or 3 To 6) (If A/T 1 To 15)	(.01°)
18	F 50 25	R1 00014 RECHECK or EXIT FINE ALIGN (RECHECK, A/T 00002 or 00003 Only) PRO To 6 (TERM) V34E To 20	
	Note:	If Present A/T Is 00002 & A Previous P57 Used A/T 00001 or 00003, ENTR To Readout Present LM Lunar Position (Step 19)	
19	F 06 89	LAT, LONG/2, ALT (TERM) V34E (ACCEPT) PRO	(.001°, .01nm)
20	F 37		